THE EFFECTS OF TINTED PLEXIGLASS
ON VISIBILITY IN
THE AH-1G COBRA AIRCRAFT

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# THESIS

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in the
AH-1G Cobra Aircraft

by

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ABSTRACT

The problem of heat reduction in the AH-1G helicopter presented several options for solution. To alleviate the problem until permanent means could be devised for airconditioning the aircraft, tinted glass was installed. This immediately caused a series of objections to the glass because of the loss of vision by pilots at night. The problem of vision loss was studied using three independent variables; color, angle of the test glass to the line of sight, and target contrast. A series of contrasting Landolt "C" rings was presented to the subjects to determine if the color or the angle of the glass, or both together, did cause a significant reduction in vision.

An analysis of variance showed no significant difference in the treatment means for the color and angle factors. The contrast factor treatment means were significant. No interaction occurred.

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## I. THE PROBLEM

With the advent of the AH-1G Cobra into the Army and Marine Corps inventories in Vietnam, new problems in operations have occurred.

When the Cobra was first introduced, no provisions were made for reducing the temperature in the cockpit when the aircraft was operated in tropical climates. During the tests of the aircraft in Texas, the temperatures were not excessive and caused no great amount of pilot fatigue. In Vietnam, however, the very high ambient temperatures and humidities caused high pilot fatigue in relatively short periods of operation. When one considered the large number of hours spent in the cockpit without pilot relief, it became imperative to reduce the temperature immediately so that aircraft safety would not be adversely affected.

To lessen the temperatures, Bell Helicópter Company fabricated and retro-fitted a blue-tinted canopy (Swedlow Plastics Co. Part No. 209-030-507-3) to the aircraft that reduced the ambient temperature in the cockpit approximately 20 degrees. Immediately, an unsatisfactory report was submitted via Army channels stating that the tinted plexiglass was not acceptable because of the loss of vision through the new canopy during night operations.[1] It was the purpose of this thesis to determine if the reduction in visibility caused by the canopy did affect the average

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[1] Interviews with Bell Helicopter Company personnel.

pilot's ability to see and to determine if the tinted glass reduced the visibility more if it were at an angle than if it were perpendicular to the line of sight.

## II. THE LITERATURE

Recent literature dealing with vision through tinted windscreens in aircraft was almost non-existent because of the opinion by professional pilots that the use of tinted glass is not a safe practice.

Several studies were available concerning the use of tinted automobile windscreens. The knowledge gained in these studies, although several years old, was directly applicable to the problem of vision through aircraft plexiglass canopies.

Automobile drivers suffer from headlight glare and excessive brightness as do pilots. Also, it was desirable to reduce the daytime vehicle temperature for driver and passenger comfort. These were the same discomforts being experienced in the AH-1G.

The blue-tinted glass used in most aircraft windscreens has a transmissibility of 70-80% as compared to clear glass, which has a transmissibility of more than 90%, according to Rohm-Haas Plastics Handbook (Ref. 1). If a pilot were operating in daylight conditions the loss of visibility would not be noticed, but under reduced light conditions the loss of light could become significant.

Wolf, McFarland and Zigler (Ref. 2) conducted experiments dealing with the effects of tinted automobile windscreens on vision at various light levels. They studied and tried to evaluate (1) the effects of brilliant light flashes on dark adaption, (2) the process of dark adaption itself, (3) visual acuity, (4) depth perception, and (5) the effects of glare on the human eye. The color of the windscreen was variable.

The results were significant. When a dark adapted subject looked through blue-tinted glass, the thresholds for recognition of a test stimulus were higher than for a less absorptive clear glass. They found that the rise in threshold corresponded directly to the loss in brightness caused by the tinted glass. When the subjects were dark adapted and were then exposed to a bright light flash, they found that the recovery time to regain the previous sensitivity level was not decreased by the tinted windscreen, as was expected. The lessening of the brilliance of the flash by the blue glass was not an advantage either because the target visibility was reduced by the same amount. Concerning visual acuity, they measured the subjects' ability to see Landolt "C" rings of different sizes. They found that the small details could be seen as well through tinted as through clear glass only if the size of the ring were 10 to 20% larger under the tinted conditions. When evaluating depth perception, they found a 25-35% loss in vision when the test target was viewed through the tinted glass. The one surprizing result was that glare was not reduced by the use of the tinted windscreen. This seems to run contrary to intuition.

In general, Wolf, et al. found that all tests showed that the eyes were less sensitive when tinted glass was used. The loss in sensitivity corresponded to the physical absorption of radiant flux by the filter in front of the eyes. No improvement in vision was found.

Both the American Standard Safety Code (Ref. 3) and Glover (Ref. 4) state that a highly desirable range of transmissibility for automobiles and aircraft windscreens, respectively, was from 70% upwards. On the basis of tests performed with glass and plastic, standards were recommended for the minimum amount of light that a transparent windscreen should transmit at various angels in respect to the line of sight. Depending on the angle of the windscreen, the minimum acceptable transmissibility was in a range from 64-89%.

Jayle, Ourgaud, Baisinger, and Holmes (Ref. 5) conclude that the need for more light appears at the age of 40 and becomes pronounced after the age of 50. They also agree that "a definite deterioration of all forms of night vision functions occurs with age." This implies that older pilots will be more affected by the loss of vision.

Heath and Finch (Ref. 6) tested various reflectance materials under the two control conditions of clear and tinted windscreen glass and found a definite loss in visibility distance through the tinted glass at night.

Contrary to the above tests by Wolf, et al. Roper (Ref. 7), and Doane and Rossweiler (Ref. 8) showed that even though visibility was reduced, the beneficial effects of glare reduction and heat absorption during daylight hours were more than sufficient to offset the loss of vision at night.

Miles (Ref. 9) has found that at luminance levels experienced during night driving, the resolving power, i.e., the ability to distinguish between objects at a distance, was drastically reduced. For a pair of targets that appeared separate at 100 feet through clear glass, the distance from the observer had to be reduced to within 25 feet when viewed through a tinted glass. When one considers the speed of modern aircraft, including the AH-1G, with dive speeds in excess of 200 knots, one can see the hazard involved.

Blackwell (Ref. 10) found a 23% loss in detection distance when viewing targets through tinted glass. Detection distance decreased with a reduction in target size but the percentage decrease with tinted glass increased much more rapidly. He felt that for safety reasons tinted glass could not be recommended.

Haber (Ref. 11), and Stone and Lauer (Ref. 12) all discovered great reduction in vision when using tinted glass at night. In addition, Haber found that when target contrast was low, percentage loss in visibility increased from 10-15% to 35-45% with a tinted windscreen.

McFarland, Domey, Warren and Ward (Ref. 13) studied the relationship of age and dark adaptation. They found a significant increase in time to adapt between young subjects and old, the times ranging from 5-50 minutes. They found that up to age 50 all subjects were dark adapted in 30 minutes or less.

## III. THE EXPERIMENT

It was desirable to equip the Cobra with the blue-tinted canopy because of its reduction in both glare and heat in the cockpit during daylight hours. Most hours are flown in daylight conditions and therefore it seemed reasonable that utmost consideration should be given to aircraft design for those conditions. However, one cannot disregard the special condition of flight that requires visual reference to the ground during hours of darkness.

The experiment of vision through tinted glass performed earlier by Wolf, et al. showed a reduction in acuity and visual distance. It was apparent that the transmissibility of the experimental glass used in those experiments was considerable less than the plexiglass used in the Cobra. Hence, the experiment performed here was designed to determine if, under conditions approximating quarter moon, pilots would be visually affected by clear or blue-tinted glass placed at two different angles.

# IV. THE METHOD

## A. EQUIPMENT DESIGN

The major problem encountered in the design of the test equipment was the development of a light source that would approximate the intensity and frequency of moonlight. The light source as developed was a small rectangular box, completely enclosed such that when placed on top of the viewing box, (Figure 1), the light illuminated the target card. A seven watt blue commercial bulb was used for the source. The blue color was used because the spectrum of moonlight is near the blue band. To use normal white light would have introduced a redness that is not present in moonlight. A Wollensak f/6, 14 inch focal length lens and a piece of frosted translucent glass diffused and reduced the amount of light coming from the bulb. The box itself was placed four feet from the target card thereby reducing the light at the card by a factor of sixteen. The intensity of the light falling on the target was $4 \times 10^{-3}$ footlamberts.

The subjects were presented a series of white cards twelve inches square upon which were drawn Landolt "C" rings of different contrast, one ring per card (see Figure 2). The cards, in decreasing order of contrast, were (1) 97%, (2) 92.5%, (3) 72.3%, (4) 56.7%, (5) 47.5%, (6) 42.5%, (7) 37.5%, (8) 32.5%, and (9) 25.0%. Commercial artist "shades of grey" water colors were used to develop the contrasts.

The contrasts were computed in the following manner: let $B_1$ be the brightness of the background and $B_2$, the brightness of the "C" ring. Then

$$C = \frac{B_1 - B_2}{B_1} (100)\ \% .$$

The brightness was measured by photometer.

The viewing box, (Figure 1), was rectangular in shape, 1 x 1 x 8 feet with an open top and viewing port at one end. The inside was painted white. Slots were placed just in front of the viewer at angles of 90 degrees and 45 degrees to his line of sight. A slot was placed at the target end of the box to hold the cards perpendicular to the line of sight.

A small red light bulb was placed at the target end of the box, on the outside, to be used by the experimentor for light in order to record responses and to make card changes without altering the night vision adaptation of the subjects. The test room was otherwise completely dark.

B. DESIGN OF THE MATHEMATICAL MODEL

There were two different colors of plexiglass, clear and blue (Co); two different angles, $90^{\circ}$ and $45^{\circ}$ (A); and nine different contrasts (C) used.

The model is a three way factorial design with replications such that

$$X_{ijk} = \mu + Co_i + A_j + C_k + CoA_{ij} + CoC_{ik} + AC_{jk} + CoAC_{ijk} + e_{ijk} .$$

Each contrast card was presented twice to a subject.

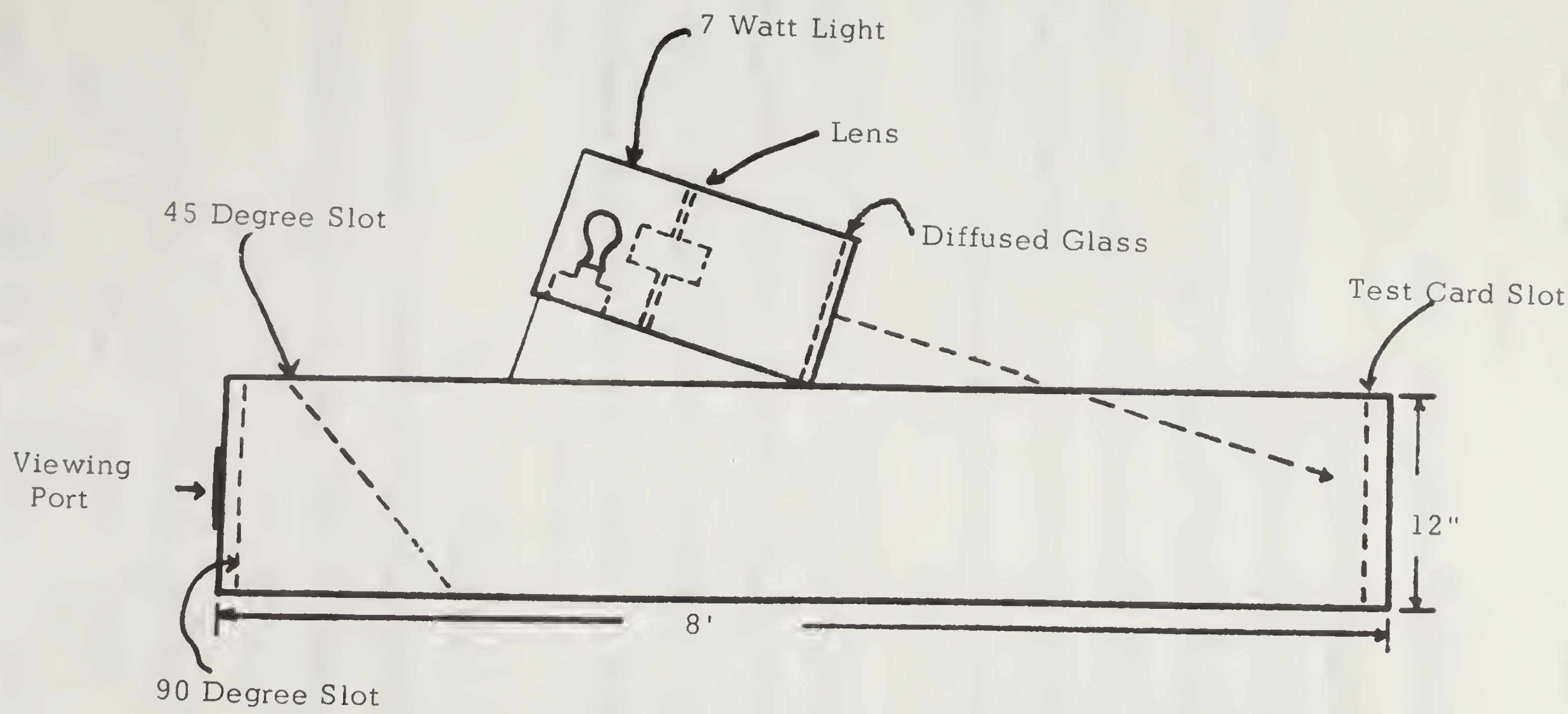


FIGURE 1. VIEWING BOX SHOWING LOCATION OF LIGHT SOURCE

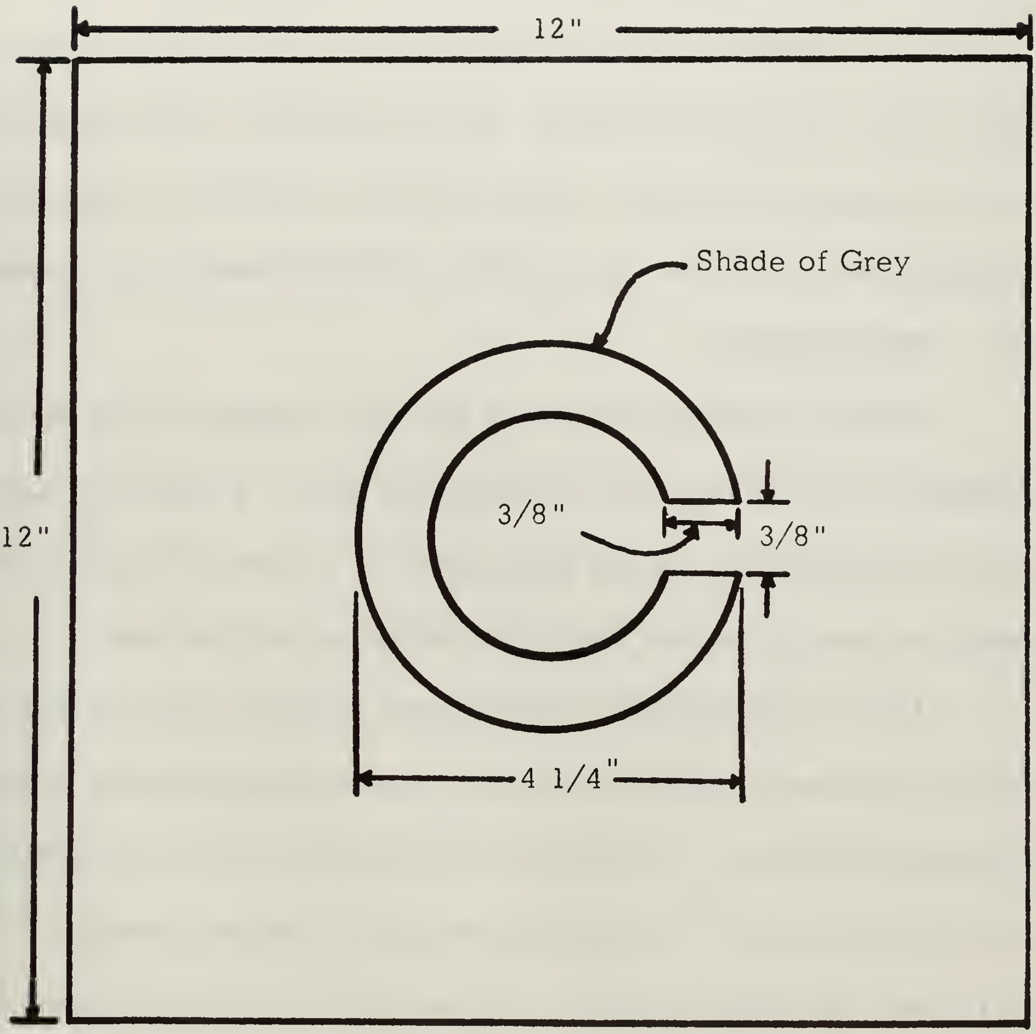


FIGURE 2. SAMPLE TEST CARD SHOWING LANDOLT RING

## C. SUBJECTS

The subjects were chosen from among the qualified aviator population at the Naval Postgraduate School. The subjects were selectively chosen so that each would have knowledge of night vision techniques and would have had experience at seeing objects at night. Also, the vision of the subjects would be normal, uncorrected and with little variance among them, hence reducing a variable in the experiment. Subjects would also be familiar with night dark adaptation procedures.

## D. PROCEDURES

Subjects were brought into a darkened lightproof room and dark adapted for 30 minutes prior to beginning tests. A small red light was used for illumination during the adaptation so that instructions could be read and demonstrations performed during the waiting time.

After dark adaptation, the subjects took their place at the end of the box and were presented a series of cards containing the various contrasting letters. The subjects were asked to tell the direction of the opening in the "C" by calling out one of the four directions: (1) up, (2) down, (3) right, or (4) left. If the subject could not discern the direction he was to say "not able." If the direction called out was erroneous or the opening was not seen, the answer was counted as wrong. The series of cards were presented in randomized order with completely randomized presentation of directions. The order of treatments was: (1) clear-90 degrees, (2) clear-45 degrees, (3) blue-90 degrees and (4) blue-45 degrees. The various subjects received the same presentation.

There was no limit placed on the amount of time spent looking at the cards prior to identification.

## V. RESULTS

One dependent variable was measured in this experiment: the number of correct identifications of the direction of the Landolt rings.

The analysis of variance performed on the three factors is described in Table I. The color and angle factors were not significant at the .05 level and there were no interactions among the variables. The differences among the treatment means of the contrast categories was highly significant at the .01 level as was expected. The results of the Duncan Multiple Range Test on the contrast variable are shown in Table II. There was no significant difference among contrasts 1, 2, 3, and 4 nor was there any between contrasts 8 and 9. Each remaining contrast showed significant difference with respect to the contrast adjacent to it in the series of cards. (See Figure 3.)

TABLE I

ANALYSIS OF VARIANCE

| SOURCE | | DF | SS | MS | F |
|---|---|---|---|---|---|
| CONTRAST | (C) | 8 | 4587.50 | 573.44 | 241.4* |
| ANGLE | (A) | 1 | 8.68 | 8.68 | 3.6 |
| COLOR | (Co) | 1 | 4.10 | 4.10 | 1.7 |
| C x Co | | 8 | 19 12 | 2.39 | 1.0 |
| C x A | | 8 | 32.95 | 4.12 | 1.7 |
| A x Co | | 1 | 3.12 | 3.12 | 1.3 |
| C x A x Co | | 8 | 7.98 | 1.00 | 0.4 |
| ERROR | | 36 | 85.50 | 2.38 | |
| TOTAL | | 71 | 4748.85937 | | |

$^*p < .05$

TABLE II

DUNCAN MULTIPLE RANGE TEST ON THE CONTRAST FACTOR

CONTRAST

| | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 0<1.55 | 1.1<1.63 | 1.2<1.69 | 5.0>1.72 | 9.8>1.74 | 15.2>1.77 | 20.0>1.79 | 20.0>1.8 |
| | 2 | | 1.1<1.63 | 1.2<1.69 | 5.0>1.72 | 9.8>1.74 | 15.2>1.77 | 20.0>1.79 | 20.0>1.8 |
| CO | 3 | | | 0.1<1.69 | 3.9>1.72 | 8.6>1.74 | 14.1>1.77 | 18.8>1.79 | 18.8>1.8 |
| NT | 4 | | | | 3.8>1.72 | 8.5>1.74 | 14.0>1.77 | 18.8>1.79 | 18.8>1.8 |
| RA | 5 | | | | | 4.8>1.74 | 10.2>1.77 | 15.0>1.79 | 15.0>1.8 |
| ST | 6 | | | | | | 5.5>1.77 | 10.2>1.79 | 10.2>1.8 |
| | 7 | | | | | | | 4.8>1.79 | 4.8>1.8 |
| | 8 | | | | | | | | 0.0<1.8 |

ERROR MEAN SQUARE = 2.375; STANDARD DEVIATION = 0.54; K = 9

| p = 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|
| 2.87 | 3.02 | 3.11 | 3.18 | 3.23 | 3.28 | 3.31 | 3.34 |

NOTE: The inequality "greater than" (>) indicates a significant difference between the mean number correct for those particular cards at the .05 level.

(a) Mean number correct for each card

| CARD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| MEAN NUMBER CORRECT | 20.0 | 20.0 | 18.9 | 18.7 | 15.0 | 10.2 | 4.8 | 0.0 | 0.0 |

(b) Dispersion of above card means on axis

| NUMBER CORRECT | 0 | 5 | 10 | 15 | | 20 |
|---|---|---|---|---|---|---|
| MEAN NUMBER CORRECT | 0.0 | 4.8 | 10.2 | 15.0 | 18.7 | 20.0 |
| | 0.0 | | | | 18.9 | 20.0 |

Note: Underlined numbers are not significantly different.

FIGURE 3. DISPERSION OF MEANS ON DUNCAN MULTIPLE RANGE TEST

# VI. CONCLUSIONS

The past literature indicates that a definite reduction in vision should occur using tinted glass vice clear. Two factors seemed to influence the inability of this experiment to determine a significant difference among the means of the variables, Angle and Color.

The first and the most important factor may have been the crudeness of the equipment, especially the contrast charts. The Duncan range test indicates that too many charts were grouped where they could give no information to the experimentor, i.e., Charts 1-4 were too close to the high contrast end of the spectrum while charts 8-9 were to close to the low contrast end. There were not enough charts in the mid-range where more were needed. The fact that the remaining charts were individually different indicates that a greater number of charts were needed in the mid range with less difference in contrast between the charts. The test would then be more discriminatory.

Secondly, it is possible that the use of blue light caused a less than normal reduction in the amount of light falling on the target cards. When a filter is used it will admit or pass light of its color, i.e., blue filters pass blue light, hence the expected filtering of light may not have occurred in the same proportion as in the previous work.

With the equipment as designed there was no loss of vision experienced by the pilots. Neither color nor angle affected the ability to see at close range.

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13. ABSTRACT

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| tinted plexiglass | | | | | | |
| night vision | | | | | | |
| aircraft canopy | | | | | | |

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